# BAT Data Analysis Software

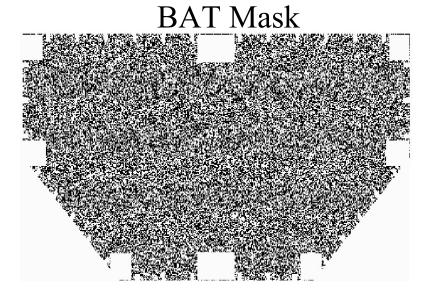
C. Markwardt U. Maryland & GSFC BAT Team, GSFC

#### Overview

- How does the BAT work?
- Dispelling some "X-ray Astronomy" Misconceptions
- BAT Flight Products
  - GRB
  - Survey
- Analysis tasks
  - Detection of new sources (imaging)
  - Analysis of known sources
  - "Science housekeeping"
- Products to expect

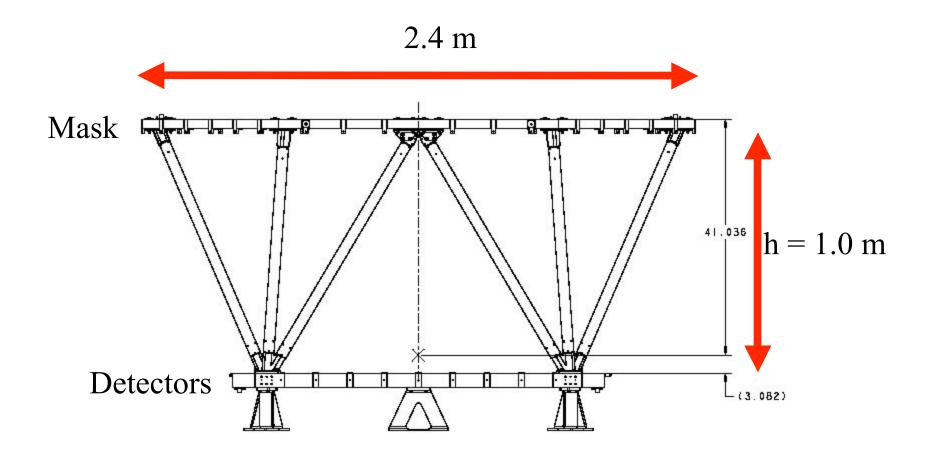
#### **How Does the BAT Work?**

- Coded mask casts "unique" shadowgram for each point on sky
- Mask tiles 5 mm random;
  cut-outs for mechanical support
- Detector array;4 mm on 4.2 mm pitch;32k detectors w/ gaps
- Point spread function ~17' FWHM;
  centroiding <1' for bright sources</li>
- Detecting new sources, analyzing known sources both require correlating the mask pattern with the detected counts



**BAT Detectors** 

## **BAT Mechanical Layout**

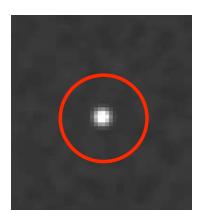


### **Avoiding "X-ray Astronomy" Misconceptions**

- No focussing optics
- Each detector can be illuminated by many points on the sky; and Each point on the sky illuminates many detectors
- CANNOT "select photons" for a source of interest as in X-ray imagers
- Two distinct spaces:
  - Detector space
  - Sky space
- Transform between two spaces with special cross-correlation software
- BAT is wide field;
  - Shadow patterns for sources in field of view will overlap
- Normally background dominated
  - 1 Crab =  $\sim$ 10% of background

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#### **Detector Space**



Sky Space

#### **BAT Flight Products**

#### GRB

- Event data  $\sim$ 10 minutes bracketing burst only
  - High time / energy resolution studies
  - Ability to make light curves / spectra during slew
  - Available at next ground station pass (few hours)

#### TDRSS

- Available in tens of seconds via GCN subscription
- Alert message for rate triggers
- Position "Ack" message for confirmed image triggers
- Light curve: 4-channel bracketing burst (includes attitude information, but no background subtraction)
- Position "Nack" for no image trigger

### **BAT Flight Products (cont'd)**

- Survey
  - When BAT is not following GRB
  - Detector Plane Histograms accumulated onboard, nominal ~5 min interval, 80-channel energy resolution
  - Only during pointings
  - Individual detector spectra are preserved (variable bin size, oversamples energy resolution)

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#### **BAT Flight Products (cont'd)**

#### Rates

- Full array: 1 sec & 64 ms (4-channel) light curves
- Per-quadrant rates: 1.6 s (4-channel) light curve
- "Mask tagged" rates:
  - 1.6 s (4-chan) light curves
  - Up to three sources of interest per field (including GRB)
  - Ground processing to reconstruct background subtracted rates
- Primarily in ready-to-use formats (OGIP light curves)

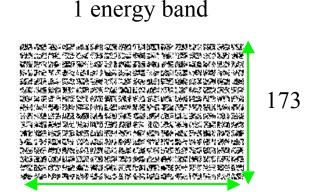
# Housekeeping

- BAT electronics are self-calibrated (autonomous pulser + Am-241 calibration spectrum)
- Array diagnostics (currents, voltages, temperatures)

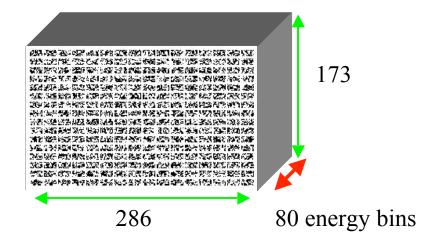
### Main New BAT Data Types

#### Detector Plane Image (DPI)

#### Detector Plane Histogram (DPH)



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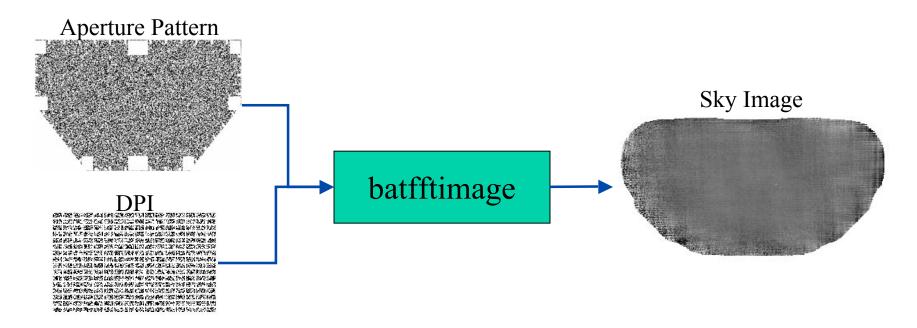


• Other formats similar to standard X-ray missions: Events, rates, etc.

#### **Main BAT Analysis Tasks**

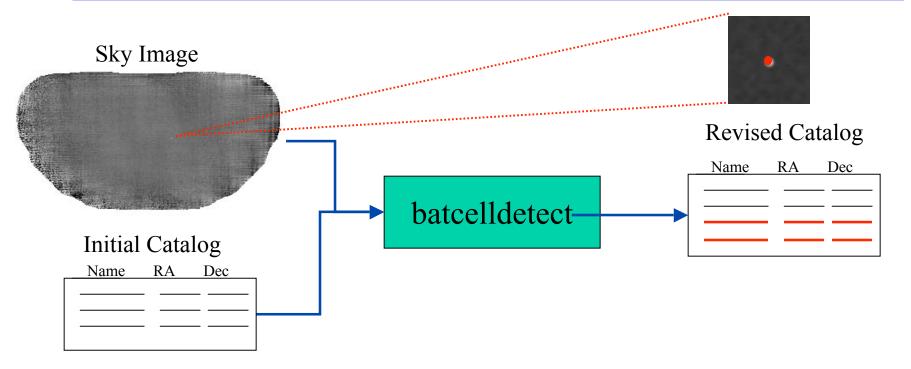
- Detection of new / known sources
  - batfftimage: Sky images
  - batcelldetect: Source detection
- Analysis of already-detected sources
  - batmaskwt{evt,img}: Mask shadow computation
  - batbinevt: Extraction of light curves, spectra
- Scientific housekeeping
  - batdrmgen: spectral response
  - bathotpix: filtering for noisy pixels
  - batfftimage: partial coding map

#### batfftimage: Sky Images



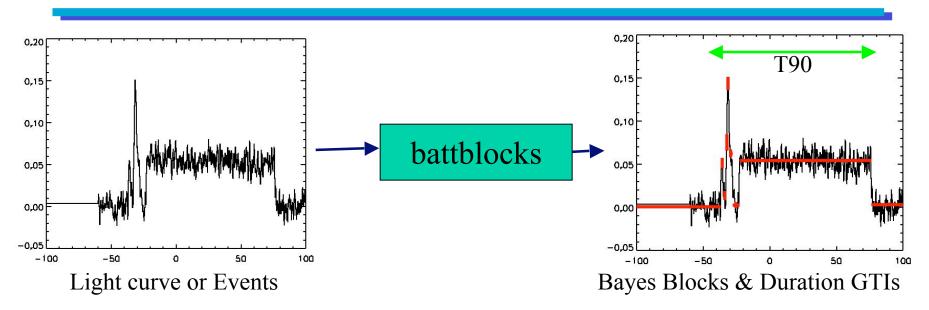
- Cross correlate mask aperture pattern with detector image (search all possible points on sky)
- Standard viewing with fv or ds9

#### batcelldetect: Detect Sources



- Detect new sources with celldetect algorithm (sliding filter), specialized for gaussian noise
- Fit PSF of detected sources
- Input: template catalog (INTEGRAL catalog accepted)
- Output: revised catalog with fluxes

#### battblocks: GRB segmentation and duration



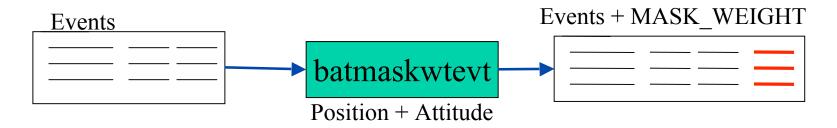
- Segment GRB with Bayesian cost function (Scargle 1998)
- Burst duration and fluence measures
  - T50/T90/Peak intervals
- Output is GTI file, can use for binning or filtering in further analysis
- Not limited to BAT data

### **Specific Source Analysis**

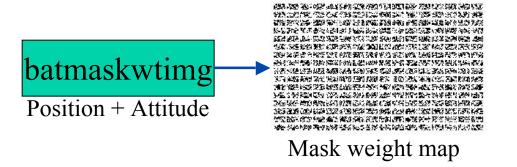
- Assumes you know source of interest (i.e. at least the position)
- Step 1: compute mask shadow weighting pattern for this position (batmaskwtevt or batmaskwtimg)
- Step 2: compute cross correlation to produce light curves or spectra (batbinevt)
- "Weighted" = Background subtracted

#### **Step 1: Mask weight calculation**

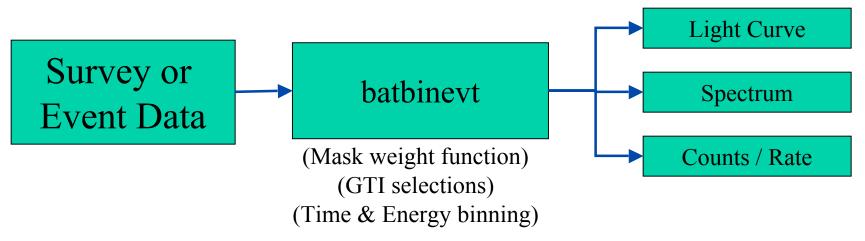
Events: batmaskwtevt



Survey: batmaskwtimg



#### Step 2: Flux (batbinevt cross correlation)



- User chooses desired time and energy binning, and output format
- Variable time binning allowed (input using GTI)
- Default units: counts per fully illuminated detector, corrected to on-axis (different pointings should be comparable)
- Pre-launch: 1 Crab = 0.039 ct/s/detector

#### batbinevt

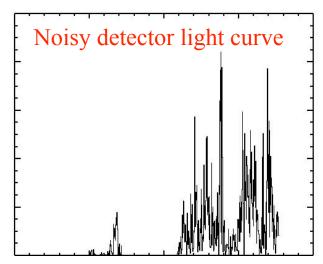
- BAT-specific task comparable to 'extractor'
- Multi-uses
  - Weighted light curves, spectra
  - Unweighted light curves, spectra, images, reformatted detector plane histograms
  - Unweighted means
    - no background subtraction
    - variations due to other sources included
- Choice of time and energy bins
- Choice of output units (counts or rate)
- Choice of output formats

### Cleaning

- Clean-type algorithm (= Iterative Removal of Sources) not fully complete
- Directly fit the detector images with template shadow and background patterns
- Will be enhanced / developed / streamlined as we gain experience with the instrument

### Science Housekeeping: Noisy Detectors

- Single noisy detectors can upset correlation
- Disabled detectors create holes in detector plane
- bathotpix task detectsnoisy pixels
  - Accepts detector plane image
  - Accept BAT enable/disable map
  - Produces quality mask
- batfftimage and batbinevt accept this mask and filter data accordingly

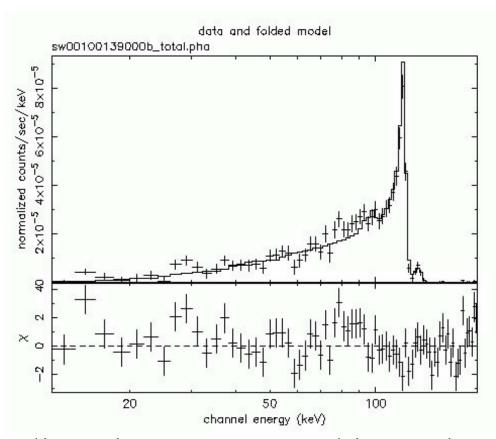


#### Science Housekeeping: Spectral Response

- batdrmgen: compute BAT spectral response matrix
  - characterized as a function of source position (source position stored in spectrum file)
- Spectra ("Type II" PHA) and RSP files are usable directly in standard XSPEC



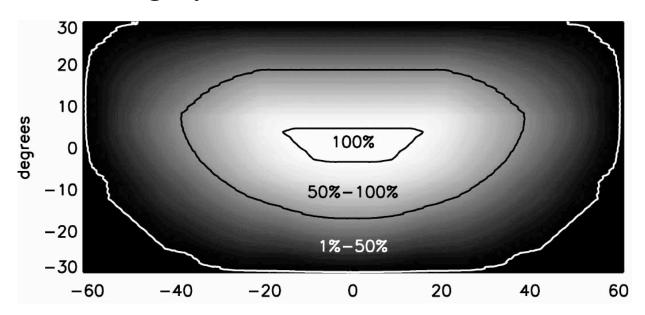
### **Example Spectrum (XSPEC Fit)**



- Co-57 radioactive source used in environmental testing (shuttered source to simulate GRB)
- Lines at 122 keV & 136 keV

### Science Housekeeping: Partial Coding

- "Partial coding" = fraction of detector plane exposed to a source
  - (varies depending on source position)
- batfftimage: has pcodemap option
- BAT images, light curves & spectra corrected for partial coding by default



### What to Expect

#### GRBs

- Light curves (several time, energy selections)
- Spectra (several time selections) + responses
- Images (pre-, during-, post-burst)
- Duration measures & segmentations
- Immediate TDRSS products
- Always
  - Standard rates, mask tagged rates per source
  - Survey histograms
  - Possibly flux determinations

#### **Conclusions**

- BAT software ready for GRB analysis
  - Source detection and Imaging
  - Temporal analysis
  - Flux / Spectral analysis
- BAT (& Swift) part of HEADAS system
  - Successor to FTOOLS, freely available
  - In development for several years in support of Swift and Astro-E2
- Calibration files delivered by standard CALDB

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